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Code 2A

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AUGUST 8, 1963

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In view of the vast amount of data accumulating from Alouette, the Canadian Topside Sounder Satellite (Chapman, 1963), it is highly desirable to establish the accuracy of this technique by comparing the electron density profiles obtained by Alouette with similar data obtained independently. This accuracy affects the geophysical interpretation of the data as well as the possibility of using the topside sounder to calibrate ground-based techniques such as the incoherent backscatter radar. There are two possible sources of errors in the electron density profiles derived from topside sounders. The first one is associated with the method of converting the observed ionograms to true-height profiles. It has now been established that topside profiles agreeing within ± 5 per cent in electron density (or within ± 15 km in terms of altitude) are obtained by using various methods of analysis which differ significantly from each other in their underlying assumptions. A more serious problem is the uncertainty due to possible deviations of the propagation paths from the assumed vertical. In some cases the presence of oblique propagation is quite obvious from ionograms whose analysis yield absurdly low values for the height of the F2 maximum. However, in the general case it may be quite difficult to assess the contribution of ray bending to the observed virtual depth and the resulting true height profile. Even matching topside and bottom soundings at the same location cannot quite resolve this uncertainty because the height of the F2 maximum (which is common to both observations) is the least accurate point determined by either sounding technique.

A much more satisfactory test of the accuracy of topside sounder measurements is to obtain a topside profile at the same time and location by an independent and reliable technique. For this reason an ARGO D-4 rocket (NASA 8.14) was launched from Wallops Island, Va. on July 2, 1963 to intersect the Alouette orbit. This rocket carried two proven experiments each yielding independently the charged particle distribution in the topside ionosphere. The electron density was measured by the well-established two-frequency CW propagation technique as used in previous high-altitude rocket flights (Jackson-Bauer, 1961); in this case using 24.5 and 73.6 Mc signals. The ion density profile was measured by an ion retarding potential experiment employing a planar ion trap, similar to that used in past rocket and satellite experiments (Donley, 1963; Bourdeau, Whipple, Donley and Bauer, 1962).

The date and time of the launching were selected to provide adequate proximity for a daytime comparison between the rocket and the satellite data. During the month of July, 1963, these requirements could be met only on the 2nd and on the 14th and in each case for a 10 minute period in the late morning. In addition, the practical requirements of the rocket flight, which yield a profile along the trajectory rather than vertically, dictated the need for stable and uniform ionospheric conditions in the area over which the comparison had to be made. The geometry and timing of this rendezvous experiment is shown in Figure 1. Although time simultaneity of the measurements could not be achieved for the entire rocket flight, it is seen from Figure 1 that the ascent data at altitudes between 300 and 600 km (corresponding to the altitude range in which the rocket data are most accurate) were obtained within minutes of the closest satellite data, and at an average horizontal distance of about 300 km. The electron density profiles derived from the Alouette ionograms were virtually identical over the latitude range from 42°N to 37°N showing that there were no significant north-south gradients in the topside over a horizontal distance of at least 500 km. In addition pre-flight monitoring of the ionospheric conditions using bottomside sounders at Wallops Island and at Ft. Belvoir had revealed uniformity in the east-west direction. Thus it appears that the requirement for a stable and uniform ionosphere was fairly well met during this test. This factor is also of importance since another comparison was planned with an incoherent backscatter measurement made near Boston, Massachusetts (42°N) by J. V. Evans.

The results of this test are given in Figure 2, which shows the charged-particle density profiles obtained by Alouette, the rocketborne CW propagation and ion trap experiments and the ground-based incoherent backscatter radar. The rocket data is most accurate for ascent and for altitudes below 700 km, as the result of the trajectory achieved. Above 700 km the horizontal component of the rocket velocity became large compared to the vertical component, which reduced the accuracy of the rocket data. In the case of the CW propagation data an obliquity correction has been made (Jackson and Bauer, 1961) which assumes that the ionosphere is stable and does not have significant horizontal gradients. Assuming an uncertainty of 10 per cent in this obliquity correction, yields an electron density error of 5 per cent at 700 km, increasing to about 15 per cent at 860 km. Below 600 km the estimated error is less than 2 per cent.

The ion trap experiment yields ion densities from the measured collector current by assuming that the rocket velocity is larger than the ion thermal velocity and that the grid transparency for ions is the same as the optical transparency, which is consistent with results of previous flights (Donley, 1963). The maximum error in ion densities is about 5 per cent (due to calibration and telemetry scaling accuracy) below 700 km and about 10 per cent above 700 km. The ion densities shown in Figure 2 include a correction which is required when the ion trap is not in the direction of the rocket velocity vector. In the upper portion of the trajectory the angle of attack of the ion trap becomes larger and this angle becomes an important factor in the analysis. The increased error in ion density above 700 km is due to the uncertainty in our knowledge of this angle of attack. No ion density data could be obtained below 367 km due to saturation of the ion trap.

The agreement between the two rocket-borne measurements, is much better at altitudes above 700 km than could be expected on the basis of the stated uncertainties of either measurement. However, this agreement must be fortuitous since comparison with the topside sounder at altitudes above 700 km reveals differences in density of at least 10 per cent, allowing an uncertainty due to analysis alone of about 5 per cent in the topside sounder profile. A more significant comparison with the topside sounder data can be made below 600 km, where the rocket data is believed to be correct within a few per cent; in this region the rocket and the satellite profiles agree within 8 per cent which is only slightly greater than the combined uncertainty of the two measurements. Although F2max was poorly defined on the topside ionograms obtained on this occasion, the height of this peak inferred from the Alouette data appears to be too low by at least 20 km, which may be due partly to errors inherent in the true height analysis and partly to a propagation effect (slight ray bending).

A normalized electron density profile (N/N_{max}) derived from incoherent backscatter measurements, assuming that T_e/T_i, the ratio of electron to ion temperature is constant, was supplied by J. V. Evans. This normalized profile gave a height for the F2 peak almost identical to that derived from the rocket data.

The backscatter profile shown in Fig. 2 was obtained by adjusting the normalized density profile at the F2 peak to agree with the rocket data. There is excellent agreement between the adjusted backscatter data and the rocket data up to an altitude of about 450 km, implying that T_e/T_i may indeed be constant over this range. The disagreement at higher altitudes could be the result of a height dependence in the T_e/T_i ratio; detailed information on this behavior must await the complete spectral analysis of the incoherent backscatter data.

Plotting the rocket data and the satellite data on a geopotential scale shows an essentially constant logarithmic slope from about 275 to 475 geopotential km, indicating an almost constant scale height, $H' = k\ (T_e + T_i)/m_i g_o$. Assuming that the mean ionic mass m_i is 16 over this height interval, the upper limit of $(T_e + T_i)$ is $2500^o \pm 150^oK$. Based upon the flux of solar decimeter radiation, the neutral gas temperature and the assumed equal ion temperature at the time of the test were estimated to be between 700 and 800^oK. Thus over this altitude region the T_e/T_i ratio would be of the order of 2.5. A comparison of the rocket and Alouette data were made with model profiles assuming a ternary ion mixture in diffusive equilibrium (Bauer, 1962). A differential least square computer analysis was performed varying the following parameters: T_i, T_e/T_i (assumed to be constant with height), and the ion concentration ratios of He^+/O^+ and H^+/O^+ at the reference level of 300 geopotential km. The best fit was obtained for values of T_i between 750^o and 800^oK and for T_e/T_i ratios between 2.3 and 2.9. The equal concentration levels inferred from this fit correspond to about 560 km for He^+ and O^+, and about 1600 km for H^+ and He^+. It should be understood that these numbers do not represent actual determinations of the transition levels (since T_e/T_i may be altitude dependent) but rather indicate that the experimental profiles are consistent with a ternary ion mixture model. In view of the fact that the experimental data used for the model comparison are for altitudes less than 1000 km, the accuracy of the upper (He^+ to H^+) transition level may be rather poor even if the assumption of a constant T_e/T_i were correct. From the analysis of the retarding potential data obtained during the rocket flight it may be possible to obtain also the variation of T_e with altitude as well as some additional information concerning ion composition. When these data, as well as the spectral data from the incoherent backscatter become available, a more detailed interpretation of the charge density profile in terms of its structure parameters may become possible.

The above discussion illustrates some of the limitations of the topside sounder data and some of the difficulties encountered in determining the basic geophysical parameters from these profiles without additional information. From the standpoint of accuracy however it can be seen that the topside sounder profile compares well with those of other established techniques. In view of its broad geographic coverage, the topside sounder satellite appears to be the most useful tool at the present time for the synoptic study of the upper ionosphere, provided the limitations of the technique are recognized and proper care is exercized in the analysis and interpretation of its data.

Acknowledgements

The authors are very grateful to Dr. J. V. Evans of the MIT Lincoln Laboratory for operating the incoherent backscatter radar during the Alouette test and for providing us with his preliminary results for this comparison.

Messrs G. H. Spaid, R. J. Hagemeyer, G. A. Talley and W. M. Daniels of the Goddard Space Flight Center were responsible for

the design and execution of the CW Propagation Experiment. The personnel of the NASA Wallops Island Station deserve much credit for achieving the very precise timing of the rocket launch which was required for the experiment.

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Figure Captions

Figure 1 - Geometry of the experiment. The heavy portion of the NASA 8.14 flight path indicates the horizontal range over which the ascent rocket data was for altitudes between 300 km and 600 km. Crosses on the Alouette flight path indicate locations and times corresponding to satellite soundings used for the comparison.

Figure 2 - Comparison of charged particle profiles obtained by rocket, satellite and ground-based incoherent-backscatter measurements. Experimental errors in the rocket and satellite data are discussed in the text.

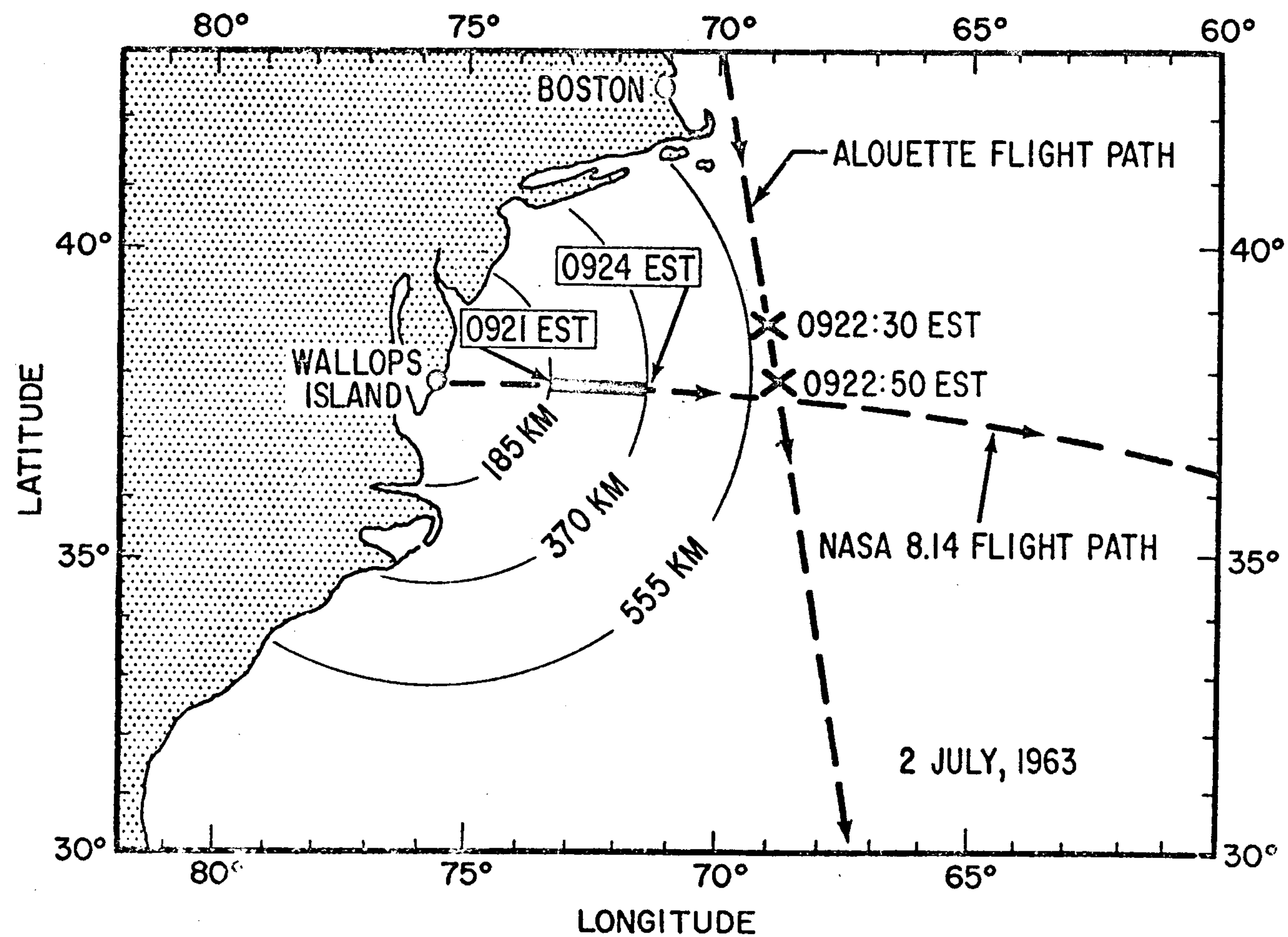
80°
75°
70°
65°
60°
BOSTON
ALOUETTE FLIGHT PATH
40°
0924 EST
0921 EST
0922:30 EST
0922:50 EST
WALLOPS
ISLAND
185 KM
370 KM
555 KM
NASA 8.14 FLIGHT PATH
35°
2 JULY, 1963
30°
LATITUDE
LONGITUDE

Figure 1

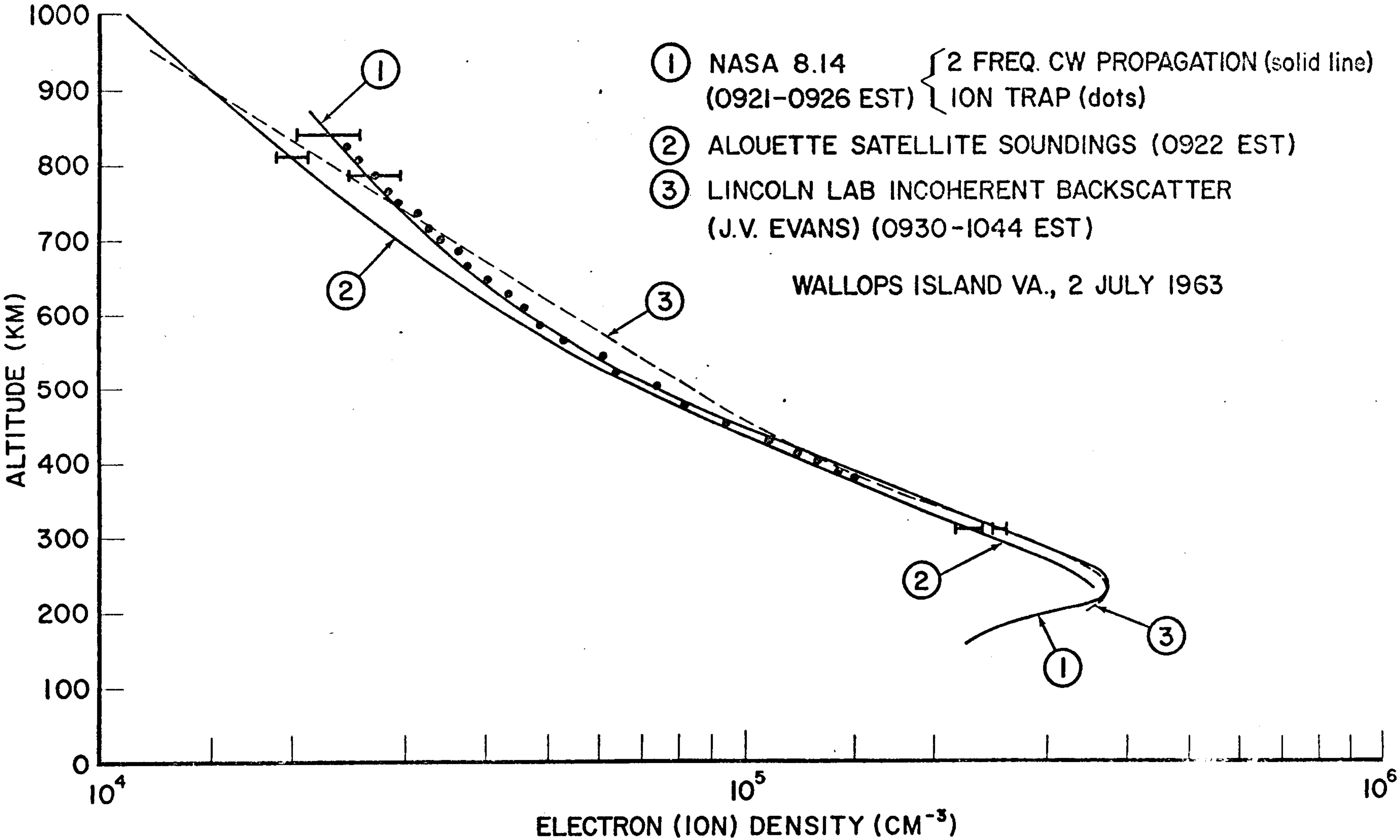
1000
900
800
700
600
500
400
300
200
100
0
ALTITUDE (KM)
1 NASA 8.14 (0921-0926 EST)
2 FREQ. CW PROPAGATION (solid line)
ION TRAP (dots)
2 ALOUETTE SATELLITE SOUNDINGS (0922 EST)
3 LINCOLN LAB INCOHERENT BACKSCATTER (J.V. EVANS) (0930-1044 EST)
WALLOPS ISLAND VA., 2 JULY 1963
10^4
10^5
10^6
ELECTRON (ION) DENSITY (CM^{-3})

Figure 2